SUMMARY OF THE EXPERIMENTAL PART OF THE XXXIVth RENCONTRE DE MORIOND.

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I summarise the experimental results presented during the hadronic session of the XXXIV Rencontre de Moriond. [a]

[a]Summary talk at Moriond, Les Arcs, 20-27 March, 1999.

1 Introduction

The XXXIV Rencontre de Moriond, the last in the current millennium, will be remembered by all of us, as the time of joy of sharing the curiosity about the processes of the subatomic world. The invariantly open character of Moriond meetings, in which mostly young promising physicists are given a chance of not only presenting results of their collaborations but also exposing their own ideas and views in an informal atmosphere, reveals unique spirit of a common cause which is often hidden during the preceding years of tedious and competitive work. On behalf of all participants I offer my thanks to the organisers of Recontres de Moriond: to their *chef* Jean Trân Thanh Vân and to his *équipe*. May these successful meetings carry on in the coming millennium.

The experimental part of the session devoted to "QCD and High Energy Hadronic Interactions" was spanned between three poles of activities. QCD, the theory of interactions of sub-hadronic coloured quanta and one of the pillars of the standard model, describes an impressively large variety of phenomena providing precise quantitative predictions. A large fraction of measurements presented at the conference were motivated by and optimised for the most precise quantitative tests of the perturbative QCD predictions. Measurements which map partonic distributions of extended hadronic objects and analyses which tried to provide comprehensible classification of non-perturbative effects represented the second pole of activities. They both establish important relationships between processes involving colliding particles of variable types and energies. The third class of measurements included those driven by pure curiosity. Most of them lay beyond the regime of applicability of perturbative QCD. With some regret, which was shared by several conference participants, I note that the fraction of Moriond-presented-results which belong to this type of activity keeps decreasing. Searches for the origins of several puzzling strong interaction phenomena are very often replaced by the "searches" of the most appropriate Monte-Carlo parameters to describe, rather than explain, these phenomena.

A large majority of results presented during the conference are summarised here, but with some embarrassment, several of the the contributions had to be left out. The results on heavy flavour decays were summarised in Guido Martinelli's concluding theory talk and are not included here. Contributions devoted to physics at future machines were omitted deliberately. Predefined scenarios of what the physics at the next generation of colliders is going to be is of non-questionable importance at the time of designing the detectors. But searches for *anticipated signatures* of new physics will have to be complemented, as soon as new colliders become operational, by searches for unexpected phenomena driven by experimentalist's curiosity and unbounded by *the Beyond the Standard Model Theory-Guides.* I would like to express the hope of several of the conference participants that the results of such searches will add a lot of excitement to the Rencontres in the first decade of the next millennium.

2 Standard Model Parameters

Measurements of the standard model parameters were extensively discussed during the electroweak session preceding the hadronic one. The most important results were summarised at the hadronic session. S. Choi [1] and T. Dorigo [2] presented the CDF and DØ measurements of the masses of the top quark and of the W boson while T. Saeki [3] discussed W mass measurements by the LEP experiments. The results of the standard model fits to the data were presented by G. Della Rica [4].

The top quark is an outstanding member of the quark family. To a certain extent it resembles more a lepton than its family fellows. In its short life, the top quark is not exposed to the colour confining forces which affect all other family members. Thus, its mass is measured with a

Table 1: Direct and indirect measurements of the W mass.

Experiment	M_W (GeV)
$p\bar{p}$-colliders (direct)	80.448 $\pm$ 0.062
LEP2 (direct)	80.370 $\pm$ 0.063
NuTEV/CCFR (indirect)	80.25 $\pm$ 0.11
LEP1/SLD (indirect)	80.326 $\pm$ 0.037

precision which can not be reached for lighter quarks. The reported average CDF/DØ mass is: $M_t = 174.3 \pm 3.2(stat) \pm 4.0(syst)$ GeV. Once the value of the top mass is fixed its production cross-section is quite precisely predicted by the standard model. The reported DØ and CDF cross-section measurements agree with the standard model expectations, extending an important test of the universality of quark interactions to five orders of magnitudes of their mass span.

The W mass measurements are summarised in Table 1. The consistency of all direct and indirect measurements is impressive, given the high precision of the reported results and allowing the LEPII measurements to be potentially affected by the colour reconnection effects and/or by correlated fragmentation of quarks originating from different W bosons. A comprehensive overview of searches for the above effects was given by W. Kittel [5]. The results of the four LEP experiments, reported by F. Martin [6], are rather confusing. DELPHI results favour Bose-Einstein correlations between pions originating from different W bosons at 2.4σ level while ALEPH results, obtained using different methods and variables, disfavour such correlations at the 2.7σ level. Moreover, only the DELPHI collaboration observes a 2σ difference of the average charged particle multiplicities of the hadronic decays of W bosons in $e^+e^- \to q\bar{q}q\bar{q}$ and $e^+e^- \to q\bar{q}l\nu$ reactions.

G. Della-Rica [4] presented an update of the standard model fits to the world data. With respect to the 1998 summer conferences two changes have to be mentioned: theoretical improvements in ZFITTER 5.20 package, which was used in the fits, and an increased precision of the M_W measurements. The fit parameters are shown in Table 2. What is particularly noteworthy is not only the remarkable success of the standard model in explaining the consistency among a large number of, *a priori* uncorrelated, measurements but, in addition, that a single, spin-less particle, with the mass of $M_H = 71^{+75}_{-42}$ GeV, predicted by the simplest mechanism of spontaneous electro-weak symmetry breaking, is both necessary and sufficient to achieve such a degree of consistency. Whether or not this particular symmetry breaking mechanism is the one chosen by Nature remains, however, to be experimentally demonstrated - there is still room for surprises here. It remains to be added that further improvements of the precision of the fit results are expected to come from the ongoing measurements of the cross-section for e^+e^- annihilation at low energies. These measurements should improve our knowledge of the electro-magnetic coupling constant α_{EM}. The preliminary results from BES - a newcomer at Rencontres - and prospects for future improvements were discussed by D. Paluselli [7].

Y. Gao [8] presented a new measurement of α_s at LEPII. The combined LEP result derived from the data taken at 189 GeV, $\alpha_s(189 \text{ GeV}) = 0.1084 \pm 0.0040$ and corresponding to $\alpha_s(M_Z) = 0.121 \pm 0.005$, agrees with the LEPI result. The energy scale dependence of α_s determined

Table 2: Standard Model Fits.

SM parameter	fitted value	direct measurement
M_t	171.7 ± 4.9 GeV	174.3 ± 5.1 GeV
M_H	$71\ ^{+75}_{-42}$ GeV	???
$sin^2\theta^{lept}_{eff}$	0.23154 ± 0.00018	0.23157 ± 0.00018
M_W	80.378 ± 0.0024 GeV	80.410 ± 0.044 GeV

using both the LEPI and LEPII data was shown to be consistent with the perturbative QCD predictions.

In QCD the strength of the coupling of quarks to gluons is independent of the quark flavour. The data collected at LEP and SLC and showed at this conference by S. Cabrera-Urbán[9] confirm this universality with a precision better than 3 %.

3 Fundamental Standard Model Processes at LEP, SLC and HERA

The measurement of the cross-section for the production of a pair of W bosons in e^+e^- annihilation provides a very important test of the standard model. It verifies the non-abelian character of the theory and tests its predicted pattern of self-couplings of the carriers of electro-weak forces. The expected centre-of-mass energy dependence of the cross-section reflects an interplay between the t-channel, ν-exchange diagram and the triple boson ZWW and γWW diagrams. The combined LEP cross-section at 183 GeV of 15.83 ± 0.36 pb, reported by Y. Uchida [10], agrees perfectly with the standard model predictions. The combined preliminary LEP cross-section at 189 GeV of 16.65 ± 0.33 pb is somewhat lower than the predicted value - although no disagreement can be claimed. The L3 preliminary measurements of the Z-pair production cross-sections at 183 and 189 GeV are in a good agreement with the theoretical predictions within large statistical errors.

C. Niebuhr[11] presented the results of H1 and ZEUS experiments on large Q^2 ($Q^2 \geq M_W^2, M_Z^2$) electron-proton and positron-proton scattering. After three years of positron runs at HERA and following the necessary upgrade of the machine vacuum system to store large electron currents the HERA detectors registered in 1998 and 1999 collisions of electrons with protons. The high Q^2 e^-p cross-section is expected to be larger than that for the e^+p collisions, both for the Neutral Current interactions (due to the positive sign of the Z^o/γ interference term) and for the Charged Current interactions (dominated at high x_{Bj} by u rather than by d quarks). Even if HERA results have little impact on precision tests of the standard model, the measured e^+/e^- cross-section ratios cross-check the magnitude of the t-channel Z^o/γ interference term and provide the first glimpse at the flavour structure of the proton in the kinematical region which is beyond the reach of the large statistics fixed target DIS experiments.

The SLD results on forward-backward strange quark asymmetry at the Z^o peak, discussed by H. Staengle [12], highlighted the merits of beam polarisation in improving the accuracy of this measurement. The reported value of $A_s = 0.82 \pm 0.13$ is in agreement with the standard

model prediction and is the most precise measurement of this quantity - in spite of the fact that the number of events used in this measurement was a factor 10 smaller than that of LEP experiments.

Another interesting SLD result reported at this conference by D. Dong [13] was the measurement of the b-quark fragmentation spectra. The reported average scaled momentum of the B-hadron of $< x_B >= 0.713 \pm 0.005(stat) \pm 0.007(syst) \pm 0.002(model)$ is the most precise direct measurement of this quantity. It illustrates the remarkable performance of the SLD CCD-Pixel Vertex Detector.

4 Searches

4.1 Exotic states

In view of the negative results of searches for the "manifestations of the 5D graviton in 4D", F. Close [14] devoted a major part of his talk to the role of pomerons in the formation of glueballs. Confronted with a "Cinderella - task" of filtering glueball candidates out of the known $q\bar{q}$ states, he argued that a sensible method of glueball hunting was to look at the initial state dependence of the observed resonance pattern. In his view, by selecting glue-enriched collisions, in particular those in which gluons have kinematicaly-enhanced coalescence probability, and by looking at the disappearance of a resonant signal for the photon-induced reactions the glueball spectrum enigma might be deciphered. A. Kirk [15] discussed the resolving power of the *coalescence filter* defined, for the reaction $h_1 h_2 \to h_1 h_2 + R$, as the transverse momentum difference of the outgoing h_1 and h_2 hadrons and interpreted by Close as the relative transverse momentum of the two recoiling pomerons. He presented the analysis of the data from the WA102 experiment and demonstrated that by selecting events with small relative transverse momentum of the two pomerons the 0^{++} and 2^{++} glueball candidates can be filtered out from the known $q\bar{q}$ resonances.

Glueball searches in $\gamma\gamma$ collisions at LEP were reported by D. Della Volpe [16]. The mass spectra were analysed using the *stickiness*, S, variable measuring the relative coupling of a resonance to a pair of gluons and to a pair of photons. The disappearance of the $\zeta(2230)$ resonance both in the LEPI and LEPII $\gamma\gamma$ data quantified by the average LEP stickiness value of $S_\zeta \geq 68$ at 95 % confidence level, establishes $\zeta(2230)$ to be a likely glueball candidate.

Are there colour singlet bound states of coloured constituents other than mesons, baryons and glueballs? QCD does not forbid the existence of hadrons composed of six quarks. As R. Ben-David [17] argued, including strangeness in constructing the colour singlet $H^o = uuddss$ state may increase the binding energy due to the colour-hyperfine interactions. The reported searches for such a state in the data of KTeV collaboration ruled out the remaining mass window for a long lived H^o as proposed by Donoghue et al. [18].

4.2 Exotic strong interaction phenomena

Traditionally the QCD-Rencontres coexist with Biology-Rencontres and the common session gives a lot of joy both to biologists and to physicists. Some of the ideas turned out, unexpectedly, to be common to both disciplines. S. Todorova-Nova [19] discussed possible experimental evidence of a (single) helix structure of the colour string proposed by Andersson et al. [18].

Modelling string fragmentation and multi-particle production processes were implicitly present in a large fraction of results reported at this conference. A silent assumption made by most of us, which is regretfully becoming a common, self-assuring consensus, is that these processes are well controlled by the available Monte-Carlo generators. Traditionally one of the basic questions of strong interaction physics: how are hadrons produced from quarks and gluons? is becoming

routinely replaced by the question: how do we get rid of or minimise the hadronisation effects considered as measurement noise for jet-spectra, W-mass and several other measurements. The LEP data on baryon production presented at this conference by R. Reinhardt [20], showing a 5σ enhancement of proton production in gluon jets with respect to the quark jets and a failure of existing generators to describe this data, reminded us once more how limited our understanding of the particle production mechanism is and ... why I included this result in the "exotic strong interaction phenomena" section of this repport.

4.3 Dedicated searches

Dedicated searches for the standard model Higgs and for new phenomena predicted by various theoretical scenarios of beyond the standard model physics were reported to give negative results. The following particles (phenomena) have not (yet) been found:

- Higgs bosons (reported by I. Nakamura [21] for LEP experiments and J.Cassada [22] for FNAL experiments);
- Supersymmetric particles appearing in MSSM, R_p violating MSSM, GMBS, SUGRA and R_p violating SUGRA (reported for the LEP experiments by R. Alemany [23], for the HERA experiments by C. Niebuhr [11] and for the FNAL experiments by R. Genik [24]);
- Technicolour, Topcolour and Flavour Universal Coloron (FUC) particles (reported by J.Cassada [22]);
- Leptoquarks and 30 different Contact Interaction scenarios (reported by C. Niebuhr [11]);
- F. Close's 5D gravitons.

The range of the above searches is indeed impressive. But what is the probability that important new phenomena, which can not be reduced to one of the above scenarios, are overlooked? In my view such a probability is larger than one might naively expect. One of the reasons is that in *the rejection-limit-optimised* dedicated searches a sizable part of the phase-space is untouched in the experimental analyses. Let me focus on two examples. All reported analyses aimed at discovering the mechanism of electro-weak symmetry breaking were limited to searches for massive, point-like, scalar particle(s) which couple to fermions with a strength proportional to the fermion masses. Consequently, only events with tagged heavy quarks were selected and searched for the presence of narrow resonances. To the same extent that this is unquestionably the optimal standard-model-guided search strategy, leaving this strategy as the only one is difficult to accept, in particular from the point of view of an experimental, "open-to-surprises" perspective. The mechanism by which fermions acquire masses in the standard model, requiring the introduction of the fermion-higgs coupling constants as arbitrary parameters of the model is, in my view, "sufficiently ugly" not to constrain the curiosity of experimentalists. As the second example, I chose searches in the high energy transfer (not necessarily correlated with the high Q^2) frontier of *ep* scattering, a phase space region unique to HERA which was largely untouched in *reported analyses* of the data. Leaving out this *difficult* fraction of the phase space has only a weak impact on the derived exclusion limits for the "standard" beyond the standard model scenarios. But, analysis of the data in this region cannot be omitted, if we want to maximise the efficiency for detecting unexpected novel phenomena rather than to establish the rejection limits for the expected ones.

4.4 Generic searches

In view of the negative results of dedicated searches several conference participants shared the opinion that *generic searches* for new phenomena should attract more attention.

The event selection criteria for such searches should, in my view, be optimised to cover those phase space regions where the standard model predictions can be made with sufficient precision to detect anomalies rather than be optimised to cover the phase space region where "anomalies are expected" and the "standard model background" is easily controlled. Generic searches diminish the chances that unexpected novel phenomena are overlooked if their manifestations in the data do not follow one of the predefined scenarios and enlarge the discovery potential if signatures of new phenomena are weak but present in more than one initial and final state topology.

An example of generic searches was given in the talk of P.Savard [25] representing the CDF and DØ collaborations. In the analysis of the production of $W + b + \bar{b}$, sensitive to single top production processes, 42 events were observed and 32 ± 5 events expected in the standard model. This is an important result for generic studies of multi-jet production accompanying the propagation of gauge bosons in the electro-weak vacuum. Complementary and, in my view, indispensable data for such studies could be collected by the LEP experiments in a dedicated large-luminosity run at the centre-of-mass energy below the threshold of the W-pair production - e.g. at 150 GeV.

Last but not least, the generic analysis of high E_T data at HERA is very interesting and the author re-encourages the H1 and ZEUS experiments to consider such an approach.

5 High E_T processes

Those of the high E_T processes, in which the total transverse energy is shared between a small number of outgoing particles and/or jets, are believed to be controlled by perturbative QCD to a high degree of precision. They define a "golden domain" for testing predictions of perturbative QCD. The results presented at this conference covered production of high E_T jets, photons, gauge bosons and heavy quarks.

5.1 Jets

The preliminary CDF Run 1B inclusive jet cross-section data presented by C. Mesropian [26] agree with the perturbative QCD predictions if one accepts a large, but quite realistic (factor 2 at $x = 0.5$), uncertainty of the gluon density in the proton. The CDF jet E_T spectra are in agreement with the DØ data within the systematic errors quoted by both collaborations. The weak x_T-dependence of the ratio of the inclusive jet cross-sections at 1800 GeV and 630 GeV, observed by both experiments at large $x_T = 2E_T/\sqrt{s}$, indicates that, if there is an excess of large E_T jets, it is related to an excess of partons carrying a large fraction of the proton momentum rather than to an increase of their cross-section in short distance processes. It is noteworthy that the measured ratios are about 30 % lower than the perturbative QCD calculations. Is the above discrepancy related to the jet production mechanism? Does it reflect the energy dependence of the energy flow uncorrelated with the production of a high E_T jet? Or, does it originate from the energy dependence of the transverse momentum of colliding partons? HERA experiments could, in my view, help not only in answering the above questions but also in constraining the large x gluon distribution. The H1 and ZEUS electron tagging detectors, which measure the energy of quasi-real photons colliding with protons, provide an experimental handle to study the energy dependent effects which could modify the jet transverse energy spectra. Similarly,

extending the measurement of the jet E_t spectrum up to 100 GeV (e.g. by accepting events in the full y and Q^2 range) could constrain the gluon distribution in the x-region of interest for interpretation of the FNAL results.

C. Glasman [27] representing the H1 and ZEUS collaborations discussed the ZEUS measurement of the inclusive jet E_T spectrum in photo-production. The data were shown to agree with the NLO QCD calculations up to $E_T < 74$ GeV (for a sample of events constrained to the $0.2 < y < 0.85, Q^2 < 4$ GeV^2 region). She also reported the H1 analysis of di-jet production in deep inelastic scattering. The gluon distribution in the $0.01 < x < 0.1$ region derived in this analysis is compatible with the one determined by the scaling violation analysis of the F_2 structure function.

5.2 Photons

The compatibility of experimental results on inclusive high E_T photon production and their interpretation in perturbative QCD was discussed by M. Krawczyk [28], M.Werlen [29] and M.G. Strauss [30] who represented the DØ and CDF collaborations.

The NLO QCD calculation by Krawczyk and Zembrzuski provides a satisfactory description of the measured E_T and η spectra of isolated photons at HERA. The NLO QCD calculations by Vogelsang et al. fail to describe the FNAL measurements of the photon spectra in the full range of the measured E_t region - even if a wide range of variation of the renormalisation, factorisation and fragmentation scales are allowed. The Gaussian smearing of partonic k_T with $< k_T >= 3.5$ GeV improves the agreement. This leads naturally to the question, 'Could NLO QCD calculations including re-summations improve the agreement between the data and theoretical predictions?'. This question will remain open until such calculations are done.

The recent critical study of the photon production processes by P. Aurenche et al. [18] and presented by M. Werlen demonstrates large discrepancies between the data from various experiments. In the low x_T region the ISR data are lower by a factor of 2 to 4 than the E706 data. The ISR data agree with the NLO QCD calculations. The E706 data, taken at a factor of ≈ 2 smaller $\sqrt{s}$, require extra Gaussian smearing of partonic k_T with $< k_T >= 1$ GeV. If the latter data are correct the question one could ask is, 'Is QCD able to predict the size and centre-of-mass energy evolution of the effective k_T smearing up to FNAL energies where $< k_T >= 3.5$ GeV?'. In the large x_T region the x_T-spectra differ by a factor of 2. This is, at present, a direct measure of the uncertainty of the large x gluon distribution.

5.3 Gauge bosons

H. Melanson [31] presented the recent results on gauge boson production at FNAL. Earlier FNAL measurements by both the DØ and the CDF collaborations, reported e.g. at Moriond-98, suggested a small excess of events in the $p_T > 60$ GeV region with respect to the theoretical predictions (both for W and, to a lesser extent, for Z boson spectra). This region is particularly interesting in view of the H1 events with large p_T leptons and missing transverse energy reported at this conference by C. Niebuhr [11]. The new preliminary DØ Run 1B results showed at this conference are in perfect agreement with $O(\alpha_s^2)$, b-space resummed calculations by Arnold and Kauffman [18]. The improvement in the measurement precision was reported to be due to "a better understanding of hadronic jets with electron signatures".

5.4 Heavy Quarks

The CDF and DØ measurements of the b-quark p_T spectra, presented by M. Baarmand [32] show very good agreement. The spectra were unfolded by the DØ collaboration from their di-muon and inclusive muon event samples and by the CDF collaboration from their J/Ψ and $\Psi(2S)$ data. Given the perfect agreement between the resulting spectra, the reported disagreement between these data and the predictions of the NLO QCD (the data lay a factor 2.5 $\pm$ 0.4 above the theoretical prediction in the central region and 3.6 $\pm$ 0.8 in the fragmentation region) challenges seriously our understanding of b-quark production processes in $p\bar{p}$ interactions within the framework of the available perturbative QCD calculations. The recent theoretical developments including the Variable Flavour Number scheme calculations by F. Olness et al. [18] and introduction of a harder $b \rightarrow B$ fragmentation function by Colangelo-Nason [18], does not provide a satisfactory explanation for the magnitude of this discrepancy.

A similar trend of the b-quark production cross-section being larger than expected was reported by M. Hayes [33] who summarised the results of the HERA experiments. The H1 and ZEUS data were compared to the LO Monte-Carlo predictions. It would be interesting to see to which extent including NLO corrections could improve or worsen the agreement between the data and the theory.

Last but not least I report the measurement of the p_T spectrum of t-quarks by the CDF collaboration presented by P. Savard [25] and look forward to the prospects of measuring this spectrum in the forthcoming RUN II at FNAL.

6 Rapidity gaps in ep and $p\bar{p}$ collisions

Events with rapidity gaps and high p_T (high mass) particles are grouped at FNAL into three classes. Events with a gap in the p or $\bar{p}$ fragmentation region are called *Hard Single Diffraction Events (HSDE)*, those with two gaps in both the p and $\bar{p}$ fragmentation regions are called *Hard Double Pomeron Events (HDPE)* and those with a single gap in the central region are called *Hard Colour Singlet Events (HCSE).*

M. Strauss [30] representing the CDF and the DØ collaborations showed the final results on the fraction of HCSE events in a sample of events containing high E_T jets. The results on the ratio of rapidity gap fractions at 630 GeV and 1800 GeV of 3.4 $\pm$ 1.2 % (DØ) and 2.4 $\pm$ 0.9 % (CDF) are in a good agreement and can be interpreted in terms of decreasing survival probability of a gap with increasing energy.

K. Goulianos [34] summarised the results of the CDF and DØ experiments. He argued, on the basis of CDF results, that the fraction of events with rapidity gaps was to a good approximation independent of the nature and of the hardness scale of the process in which rapidity gaps were created. The list of these processes included: W-production, di-jet production, b-quark production and J/ψ production. The jet E_T spectra were reported to be compatible for double pomeron exchange, hard single diffraction and non-diffractive classes of events. In addition the relative "HDPE"/"HSDE" and "HSDE"/"ALL" fractions were found to be the same within experimental errors.

The processes producing leading baryons and/or rapidity gaps in ep collisions at HERA were discussed by M. Martinez [35] in a formalism based on the $F_2^{D(3)}$, $F_2^{LN(3)}$ and $F_2^{LP(3)}$ structure functions. Leaving aside the controversial formalism used in the analysis, the data clearly demonstrated that the mechanism producing rapidity gaps, leading protons or neutrons is decoupled from the process of deep inelastic collision of the projectile electron with one of the charged soft partons. This statement is more general than the the Regge-motivated factorisa-

tions of $F_2^{D(3)}$, $F_2^{LN(3)}$ and $F_2^{LP(3)}$ and, in particular, does not preclude a specific ordering of reggeon formation and deep inelastic electron-reggeon collision.

In my view, both the HERA and Tevatron data provide increasing evidence that in a large variety of hard diffractive processes the same point-like structure of the vacuum excitation is probed. This structure appears to be universal i.e. independent of whether a particular de-excitation mode produces rapidity gaps, leading neutrons or protons. Such universality can be extended to other modes provided that they are not correlated with the azimuthal angle of the hard scattering plane. It is my hope that the experimental studies of such low-frequency lepton-induced de-excitation modes of the QCD media of variable colour-field strength (generated by nuclei of variable atomic number) will give in the future an important boost in our understanding of QCD at large distance scales.

7 Structure functions

7.1 Nucleon.

The measurements of the double differential cross-section $d\sigma/dxdQ^2$ in electron-proton scattering cover a very impressive range of the (x, Q^2) domain. M. Costa[36] presented the results from ZEUS and H1 experiments which extend the measurements to the low $Q^2 \geq 0.065$ GeV^2 region. After several years of continuous progress in improving the accuracy of the data the point-like charge structure of the proton is mapped with high precision by the HERA experiments. On the other hand, unfolding the relative contributions of the photo-absorption cross-section for longitudinally and transversely polarised photons and interpreting the resulting structure functions in the framework of QCD, in particular in the low x domain, are not free of ambiguities.

The method used by the H1 collaboration to determine the contribution of longitudinal photons to the measured cross-section is, in my view, controversial and cannot replace the conventional Rosenbluth separation method which requires varying the HERA beam energy (-ies). The reported success in applying the DGLAP equation to describe the Q^2-evolution of the measured F_2 structure function down to Q^2 values as low as 1 GeV^2 can hardly be considered as equivalent to confirming its underlying partonic dynamics. The DGLAP fits of the deep inelastic scattering data have substantial freedom in absorbing a wide range of "non-DGLAP" Q^2-shapes of F_2 by the fitted x_{Bj}-shape of the gluon distribution at fixed Q_o^2 scale - in particular in the low x_{Bj} region where the Q^2 span of measured F_2 values is small. The x_{Bj}-shape of the gluon distribution at $Q^2 = 1$ GeV^2, showed by M. Costa[36] is in my opinion sufficiently "unphysical" to indicate that non-perturbative scaling violation effects and/or non-linear QCD effects e.g. those discussed at his conference by R. Venugopalan[37] are present in the data.

Another result which, in my view, raises serious doubt on the applicability of the DGLAP equations for HERA data below $Q^2 = 10$ GeV^2 was presented in a talk by G. Marchesini's[38] on new developments in power corrections. One of several issues discussed in this talk was the Breit-frame analysis of the fragmentation spectra of the current quark in deep inelastic scattering. The power corrections to the quark fragmentation function modify, in this kinematical region, the NLO QCD predicted values by factors up to 20. Leaving aside explaining the source of such large corrections[a] their impact on the F_2 values determined by methods based on the measurement and QCD-Monte-Carlo simulation of the hadronic system must be large. Why are there no traces of these large corrections in the comparison of F_2 values determined using electron and hadronic methods?

[a] I devoted a large fraction of my talk at the recent RIKEN Workshop on "Hard Partons in High Energy Nuclear Collisions" to this issue.

I would like to summarise the discussion of the HERA deep inelastic scattering results by two conclusions. The first is that one should use with caution the existing parametrisations of the gluon distribution in the very low x region. The second, optimistic one, is that we may have already entered a new QCD regime of saturated partonic densities.

The QCD analyses of deep inelastic scattering data sets leave a substantial uncertainty in the derived gluon distribution not only at low x but, as discussed by A. Ball [39], as well at large $x \geq 0.3$. In this region non-perturbative effects are absorbed, by common conventions rather than by common understanding of their size, into higher twist and target mass corrections. The *a priori* unknown size of higher twist corrections[b] give rise to an uncertainty in assigning a fraction of observed Q^2 evolution of the cross-sections to perturbative, gluon mediated processes. The relative importance of perturbative and non-perturbative contributions to structure functions were discussed by S. Alekhin [40] who presented a new analysis of the fixed target deep inelastic scattering data. As an example, the leading twist contribution to $R = \sigma_L/\sigma_T$ at $Q^2 = 2$ GeV^2 and $x_{Bj} = 0.5$ is below 10 % of the measured value. It illustrates how loosely the x-distribution of the gluon is constrained by a rather precise R measurement.

Global QCD fits of a large variety of hard process data, provide the input parton distribution functions for commonly used Monte-Carlo generators. In addition they cross-check the consistency of data sets which cannot be directly compared. A. Ball [39] reported recent news coming from this field of activity. He expressed his vision of the bright future by quoting D. Kosower's: "...end of the tyranny of the global fitters" call at the recent La Thuille conference and by explaining a new fitting method which, in my view, could create "*a brave new world* of data sets" for fitters. The new method re-addresses a very important and very difficult problem: how to include correlated systematic experimental errors in the fitting procedure in order to properly assess the size of systematic errors of the resulting partonic distribution functions? This has been a controversial subject over the last 15 years and will most likely stay controversial. Instead of addressing technical aspects of the old and new method let me present the following *phenomenological* observation which shifts the centre-of-gravity of the problem. Contrary to *old-fashioned expectations*, the "quality" of several deep inelastic data sets which determine the partonic distribution functions, appears to be proportional to the number and the size of experimental corrections determined with the help of QCD Monte-Carlo simulations, which leave no traces in the error matrices of the data points.

7.2 Polarised nucleon

The preliminary results of the E155 experiment were reported by R. Erbacher [41]. They included measurements of the g_1 and the g_2 structure functions of the proton and of the deuteron and the results of the NLO QCD fits to the data. The Bjorken sum rule is confirmed by the high precision data. The measured $\Gamma_1^{p-n} = 0.172^{+0.005}_{-0.003}\,^{+0.008}_{-0.007}$ agrees with the predicted value of $\Gamma_1^{p-n} = 0.182 \pm 0.005$.

An attempt to directly determine the contribution of gluons to the spin of the nucleon has been made by the Hermes collaboration and reported by J. Martin [42]. Their value of $\Delta G/G = 0.41 \pm 0.18(stat) \pm 0.03(syst)$ however relies heavily on the modelling of hadron production processes in ep scattering down to $p_T = 1.5$ GeV. The PYTHIA Monte-Carlo was used to determine the relative contributions of photon-gluon fusion, QCD-Compton and soft VDM processes to the observed p_T spectra of charged hadrons.

[b] An ambitious program aiming at understanding the magnitude of such corrections was presented by G. Marchesini [38].

7.3 Photon and Virtual Photon

Measurements of the leptonic photon structure function $F^{\gamma}_{2,QED}$ by the OPAL and L3 collaborations were presented by M. Chamizo [43]. This structure function, contrary to the hadronic photon structure function, can be derived within QED. It is interesting to note that, the average virtualities of the probed photon of $< P^2 >= 0.034$ GeV^2 (L3) and $< P^2 >= 0.05$ GeV^2 (OPAL), required to achieve good agreement between the theoretical prediction and the data are both compatible with $4 * m_\mu^2$ and that the contribution of longitudinal photons can not be neglected.

M. Chamizo [43] showed discrepancies between the theoretical predictions and the measurements of the hadronic photon structure function $F^{\gamma}_{2,QCD}$ by LEP experiments. Discrepancies were also reported by T. McMahon [45] who presented measurements of the di-jet cross-section in photo-production at HERA. It will be interesting to see if they could be absorbed into a new set of partonic densities of the photon which would describe both the HERA and the LEP photon-structure-dependent observables.

Production of jets in deep inelastic ep scattering, in particular in processes in which a jet is emitted at a large $\Delta\eta = \eta_{jet} - \eta_{QPM}$ have attracted considerable attention at HERA. These processes have been expected to provide evidence for so called "BFKL-dynamics" - one of buzz-words at HERA. M. Swart [44] representing the H1 and ZEUS collaborations showed the comparison of the jet spectra with the recent NLO QCD calculations by B. Poetter [18]. Good agreement was found at the price of introducing a non-perturbative structure of the virtual photon. T. McMahon [45] used the H1 di-jet production data to determine the effective partonic densities of the virtual photon in the "Leading Order Single Effective Subprocess Approximation". One of several possible conclusions from the above studies, for those who find it difficult to accept absorbing our lack of understanding into a new set of structure functions, is that HERA processes with two hard scales Q^2 and p_T^2, keep on challenging perturbative QCD.

7.4 Pomeron

The pomeron structure function $F_2^{D(2)}$ and its partonic interpretation based on the fits to the H1 rapidity gap data were discussed by M. Martinez [35]. The pomeron is mostly glue: at $Q^2 = 4.5$ GeV^2 90 % of the pomeron momentum is carried by gluons. This fraction is comparable to the fraction of the proton momentum carried by gluons in the low x_{Bj} region where the bulk of rapidity gap events is observed.

How universal is the measured pomeron structure? Can one use partonic densities of "HERA pomerons" in other diffractive processes? Do we need to introduce pomeron partonic structure to describe diffractive processes at all? There are two reasons why I ask these questions. The first boils down to an aesthetic "Occam-razor" argument, which forbids adding the pomeron to the list of hadronic objects with distinct partonic structures before verifying if such structure cannot be simply derived from those already included in the list. To my best knowledge no compelling experimental evidence has been presented so far by the HERA experiments that the pomeron structure cannot be explained by the proton structure at $x_{Bj} = \beta x_{pom}$ and fixed Q^2. The second one is driven by an experimental observation presented at this conference. It is natural to expect that the partonic structure of pomerons produced at HERA is sufficiently universal to be applicable to rapidity gap processes observed at FNAL. The preliminary analysis of the data of the CDF collaboration on jet production in rapidity gap events which was reported by K. Gulianos [34] indicated that this might not be the case. The comparison of the data with the predictions based on partonic distributions of the "H1-pomerons" showed large *β-dependent*

discrepancies suggesting a lack of such universality. Even if these discrepancies can eventually be be explained by the subleading reggeon trajectories such phenomenology becomes hardly predictive and of rather limited merit.

8 Strong interactions in nuclear media

P.Seyboth's [46] statement summarises best the experimental results on heavy ion collisions. He said that "the SPS data were *probably compatible* with a QGP phase transition but the efforts of experimentalists to provide confirmation of a clear threshold in energy or nuclear size and the efforts of theorists on alternative interpretations of the observations have to be pursued".

L.Kluberg[47] presented several consistency checks of the data of the NA50 experiment. One of the most important was the analysis of the target length dependence of the ratio of J/Ψ to Drell-Yan cross-sections. Suppression of J/Ψ production in Pb-Pb central collisions (with respect to extrapolations from lighter nuclei) was demonstrated to be robust against several experimental checks. Whether it can be considered as a signature of the phase transition remains an open question. I would like to remind the reader at this point that the impact parameter dependence of the ratio of quark and gluon distributions in large nucleus, has never been measured. This ratio determines the relative strength of Drell-Yan and J/Ψ production. Its extrapolation to central Pb-Pb collisions, using only the impact-parameter-integrated A-dependent quark distributions, is a subject of uncertainty which, in my view, cannot be precisely assessed at present.

The CERES results on e^+e^- production in p-A and A-A collisions have been reported by T. Wienhold [48]. Their theoretical analysis was presented by H. Hansson [49]. The enhancement in the e^+e^- mass spectrum with respect to pp-scaled sources in the region of $0.25 < m_{ee} < 0.7$ GeV of $3.9 \pm 0.9(stat) \pm 0.9(syst)$ observed in the 1995 data is confirmed by the 1996 data (the reported excess is $2.6 \pm 0.5(stat) \pm 0.5(syst)$). The model which was used in the extrapolation agrees very well with e^+e^- mass spectra observed in p-Be and p-Au collisions. The particle ratios were taken from a thermal model fitted to the measured ratios in Pb-Pb collisions. The enhancement is most pronounced at low p_T of the pair: $p_T < 0.5$ GeV.

In Quark Gluon Plasma (QGP) one expects the relative multiplicity of strange versus non-strange particles to increase with increasing strangeness content of produced baryons. The WA-97 data presented by P. Norman [50] exhibited clearly such a behaviour. However, this explanation of the data is not unique. The Dual Parton Model analysis presented by C. Salgado [51] explains the hyperon yields by standard non-QGP processes. In addition, A. Rybicki [52] showed that the strangeness enhancement was observed already in the central p-Pb collision NA49 data in the fragmentation region in contradiction to the VENUS Monte-Carlo predictions.

One of the most interesting measurements presented at the XXXIV Moriond was the first deuteron , anti-deuteron and triton coalescence results of the NA44 collaboration discussed by J.J. Gaardhoje [53]. Low energy anti-dueterons can be very efficiently identified by NA44 by using the standard time-of-flight method and, in addition, by measuring the excess of energy deposited in the calorimeter due to the extra energy released in the $\bar{d}$ annihilation. In order to produce deuterons (anti-deuterons) the recombination of nucleons (anti-nucleons) must take place at the very late stage of particle production phases so as not to disrupt such loosely bound nucleon system. The freeze-out radius was shown to be compatible with the interferometric measurement of the size of the pion source.

The nucleus can be used as a femto-vertex detector in studies of the space-time structure of strong interactions, in particular in processes with point-like leptonic probes. The HERMES eA data on ρ production presented by T. Shin [54] showed evidence for the variation of the nuclear transparency ratio with the coherence length.

9 Concluding remarks

Investigation of "colourful" strong interaction phenomena is sufficiently challenging to give us a lot of fun. While the experimental studies of electro-weak phenomena put an emphasis on the detector design and performance, optimised for the highest possible accuracy of *the predefined measurements*, the research in the strong interaction domain, in particular in its most challenging *confinement and QCD-vacuum sectors*, need, first of all, a fresh, curiosity-driven, and open-to-surprises look at the data.

The lack of theoretical guidelines in defining "appropriate variables" which could link short-distance and long-distance, strong interaction phenomena makes this task hard. But, at the same time it gives us, experimentalists, a challenging chance to use our imagination rather than our fingers attached to the workstation keyboards while scrutinising the agreement between the corresponding "Ntuple variables" of the Monte-Carlo and the data.

Moriond meetings stimulate the atmosphere, in which admitting the lack of understanding rather than hiding it under the cover of self-assuring consensus is of value. They give us the necessary enthusiasm to face the challenges. Moreover, they create hope that the forthcoming studies of strong interaction phenomena will keep on bringing new interesting and unexpected results for the next millennium Rencontres.

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